Modeling Errors in Taxiing of Commercial Aircraft

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Overview

- Background
  - The problem
  - Modeling framework
- Structure of the model
  - Cognitive model
  - Physical and environmental models
- Sources of error
- Work in progress/future extensions
- ACT-R issues

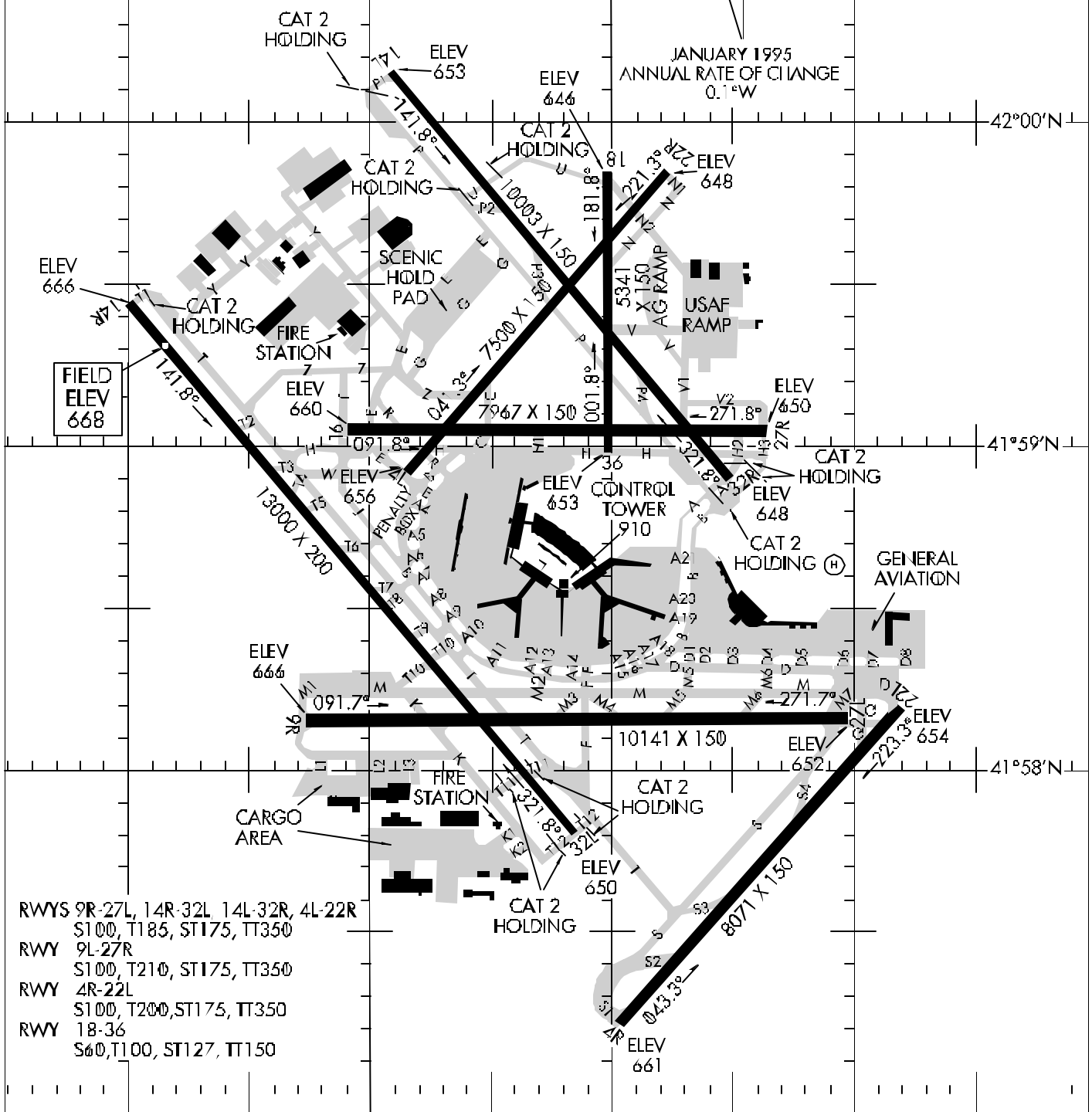
The Problem

- Taxiing (runway <—> gate) is the phase of commercial flight that is least automated
- Since 1972, 11 runway accidents have claimed 719 lives
  - Not counting Milan accident this fall
- Runway incursions have increased 15% per year for the last four years in the U.S. alone
  - The bulk of this increase is attributed to “pilot deviations”

The Study

- Based on NASA Ames studies of flight crews taxiing at Chicago O'Hare (e.g. Hooey, Foyle, Andre, & Parke, 2000)
  - Bad visibility (fog)
  - Fairly high error rate (~22%)
    - 6 crews, 9 runs each, 12 total major errors
    - 2 Communication errors (e.g., wrong taxi route understood)
    - 6 Local decision errors (e.g., decision to turn left when right is correct)
    - 4 Execution errors (e.g., misinterpreting signage)
- Follow-up studies showed expensive technology (EMM, HUD) drastically reduced error rate
  - Cheaper or easier way?

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.


JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
42°00'N
41°59'N
41°58'N
CAT 2 HOLDING
ELEV 653
ELEV 646
ELEV 648
ELEV 666
ELEV 660
ELEV 650
ELEV 656
ELEV 653
ELEV 648
ELEV 666
ELEV 654
ELEV 652
ELEV 650
ELEV 661
FIELD ELEV 668
SCENIC HOLD PAD
FIRE STATION
USAF RAMP
AG RAMP
5341 X 150
10003 X 150
7500 X 150
7967 X 150
13000 X 200
10141 X 150
8071 X 150
CONTROL TOWER 910
PENALTY BOX
GENERAL AVIATION
CARGO AREA
141.8°
181.8°
221.3°
001.8°
041.3°
091.8°
271.8°
321.8°
223.3°
043.3°
RWYS 9R-27L, 14R-32L, 14L-32R, 4L-22R
S100, T185, ST175, TT350
RWY 9L-27R
S100, T210, ST175, TT350
RWY 4R-22L
S100, T200, ST175, TT350
RWY 18-36
S60, T100, ST127, TT150

General Approach

- Traditional cognitive approaches
  - History of modeling static laboratory tasks
  - Now ready to handle complex, dynamic environments
  - Approximate quantitative models
- Traditional ecological approaches
  - Abstract description of task environment
  - Role of human cognitive (& perceptual-motor) capabilities minimized due to lack of quantitative models
- Our goal: Unify the two approaches
  - Cognitive model informed by environmental analysis

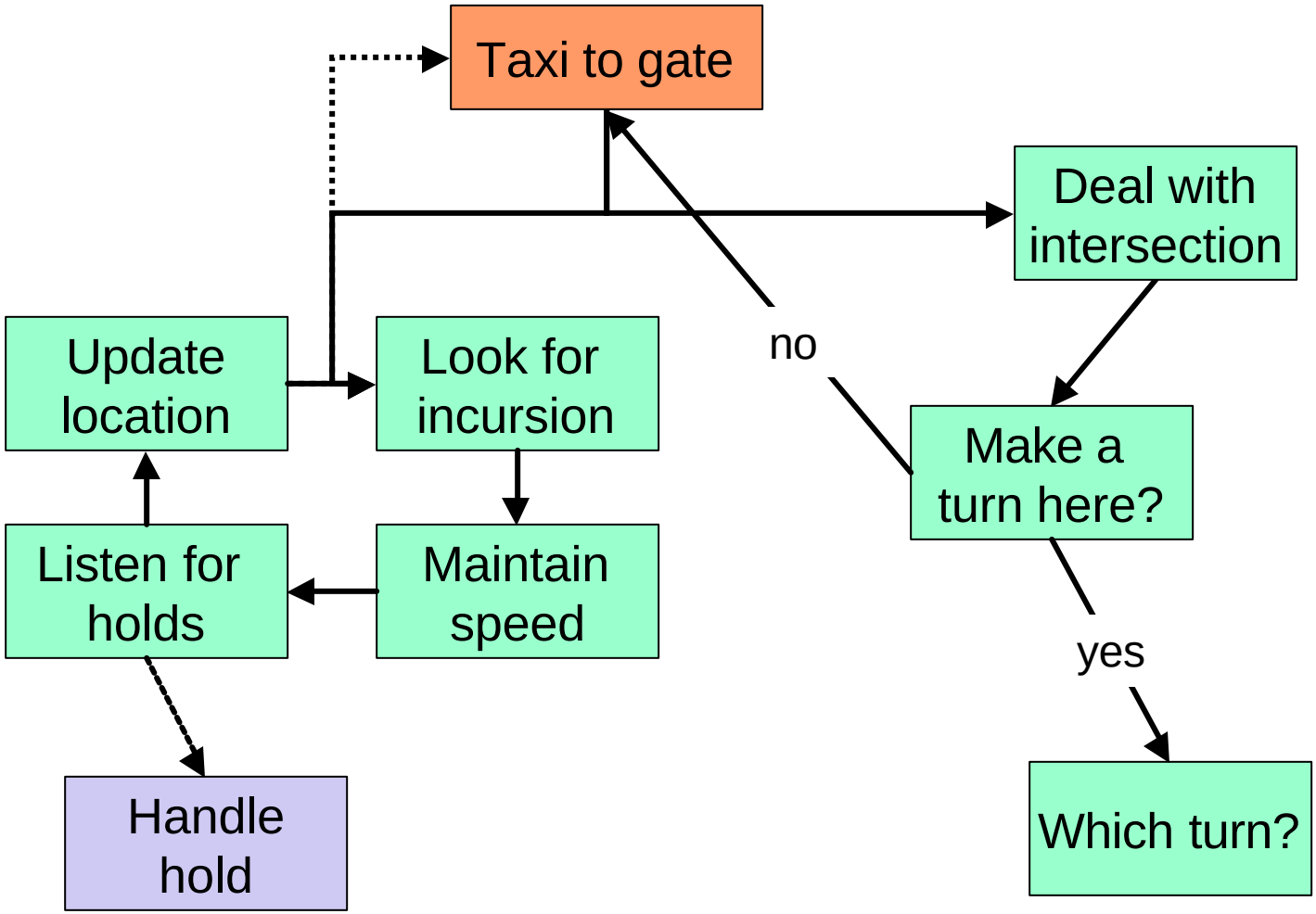
Integration

- Use environmental analysis/model to provide the ACT-R/PM model a realistic environment of operation
  - For example, realistic time constraints based on model of aircraft dynamics
- Use environmental analysis (based in part on SMEs) to:
  - Identify problem-solving and decision-making strategies
  - Set parameters in ACT-R representing the information landscape for those strategies
    - Frequency and recency
    - Success rate and costs

Model Scope

- Model of single individual, the captain, and the environment
  - This is an ACT-R 4.0 model
- Currently, we do not model the FO
- Also, no model of errors resulting from miscommunications between agents
- Does not model low-level control of steering
  - Airport is a series of “rails”

Cognitive Model Overview



Maintenance Goals

- During routine (straight) taxiing, all these goals will regularly be made the focus
- When one of these goals completes, it can return information to the top goal
  - Example 1: If an incursion is detected, it will return a note to the main goal to next push a goal to handle the incursion
  - Example 2: Updating location might determine that there's an intersection coming up, which will return a note to the main goal to deal with it
- Satisfying these goals takes time

Make a Turn Here?

- This can be very simple:
  - If the intersection coming up is a “T” then a turn must be made
  - Otherwise, model generally relies on memory of turns to decide whether to turn
    - Expectancies can play a role here
- This is a potential error source
  - Makeup of errors suggests that this is uncommon as a decision error (only made once), more common as a planning error

Which Turn?

- Model explicitly chooses a strategy for determining which turn to make
- Different strategies have different time demands
- Thus, model is sensitive to environmental constraints
  - Aircraft dynamics
  - Sign placement
  - Taxiway geometry
- Considers time cost and rough success rate information
  - Most accurate strategy given time available (e.g. Payne, et al.)

Turn Decision Strategies

- Strategies available:
  - Remember
    - Fast, increasingly inaccurate
  - Turn toward gate
    - Not quite as fast, surprisingly accurate in most airports
  - Turn which reduces larger of XY distance
    - Moderately fast, much more accurate than you'd think
  - Derive from "map knowledge"
    - Slow
    - High accuracy in principle, but still error-prone
- Buy time and re-assess (brake)

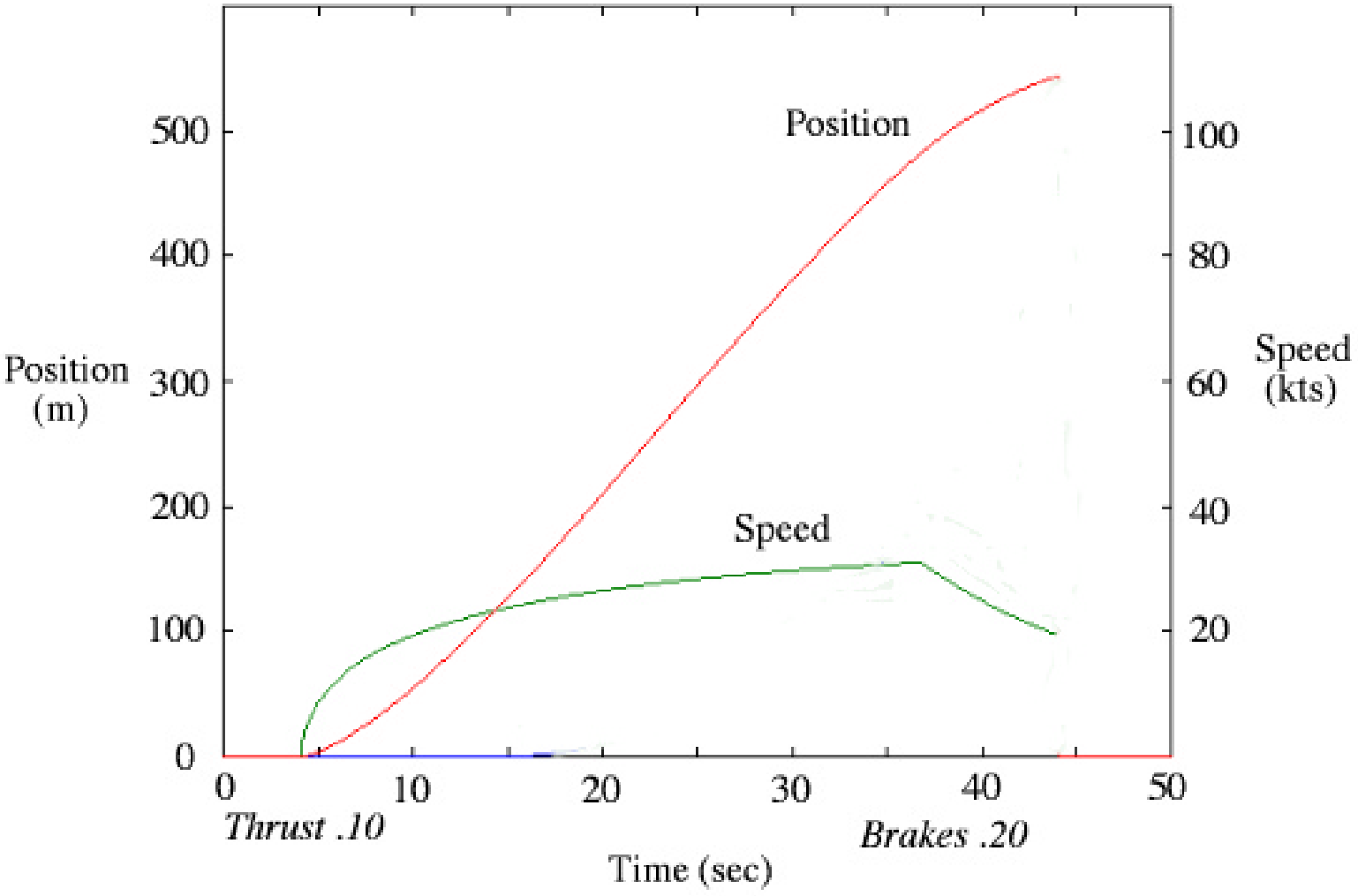
Turn Execution

- Speed in a turn is determined by
  - Turn radius (hard, 90, soft)
  - G-force limitations (guideline is 0.25 g's)
- While we don't model the control movements made by the pilot during the turn, we assume that this requires visual guidance
  - We "lock" the visual system to the relevant yellow line during the turn

Physical Model

- Model of physical aircraft based on
  - Dario's Nissan car simulator
  - Aircraft specifications from Boeing and NASA
  - Adjustments from physics first principles
- This model determines
  - Acceleration
  - Braking
- Because time is such an important resource to the cognitive model, it is critical to get this right

Physical Model Performance

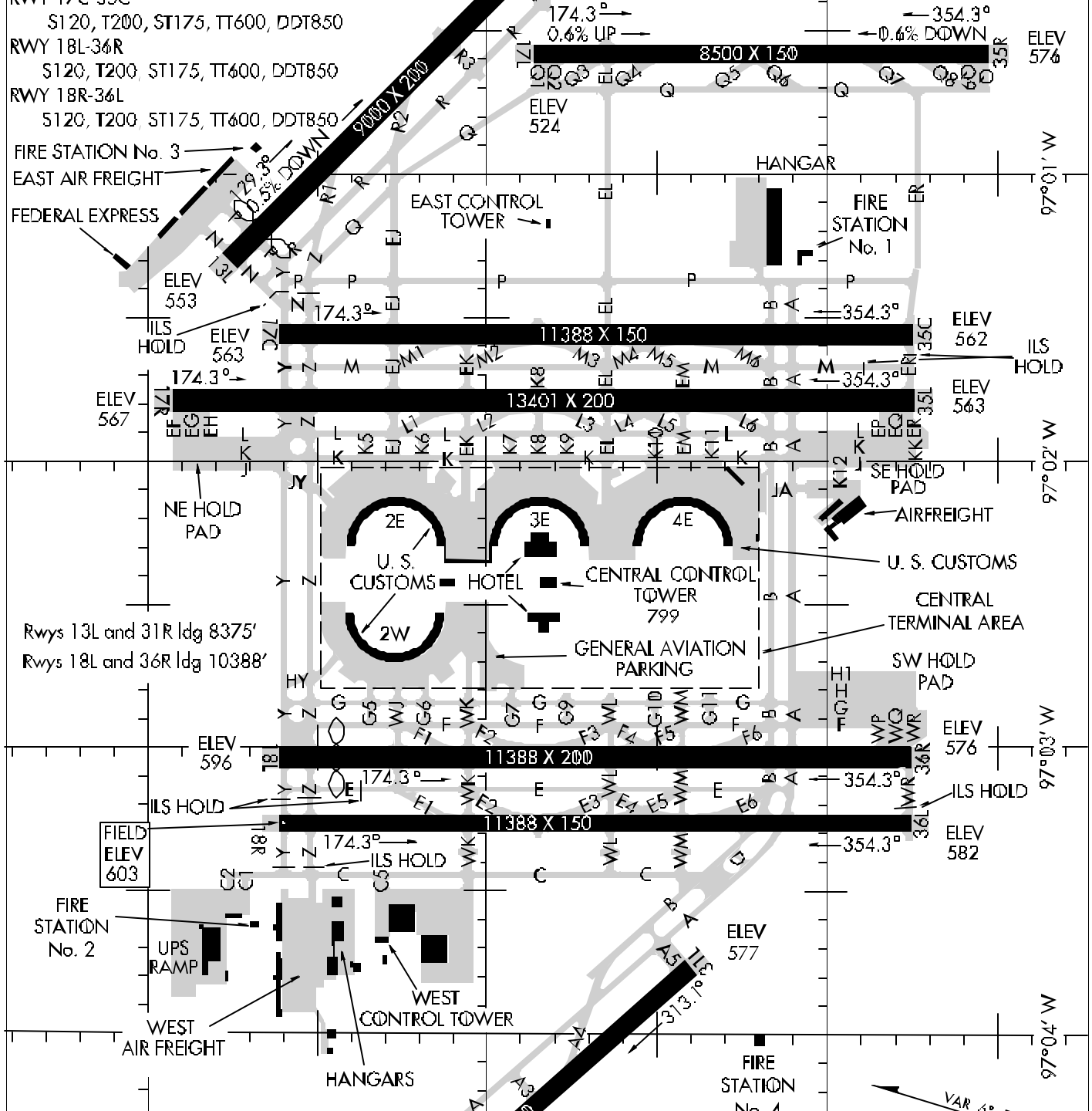


Visual Environment Model

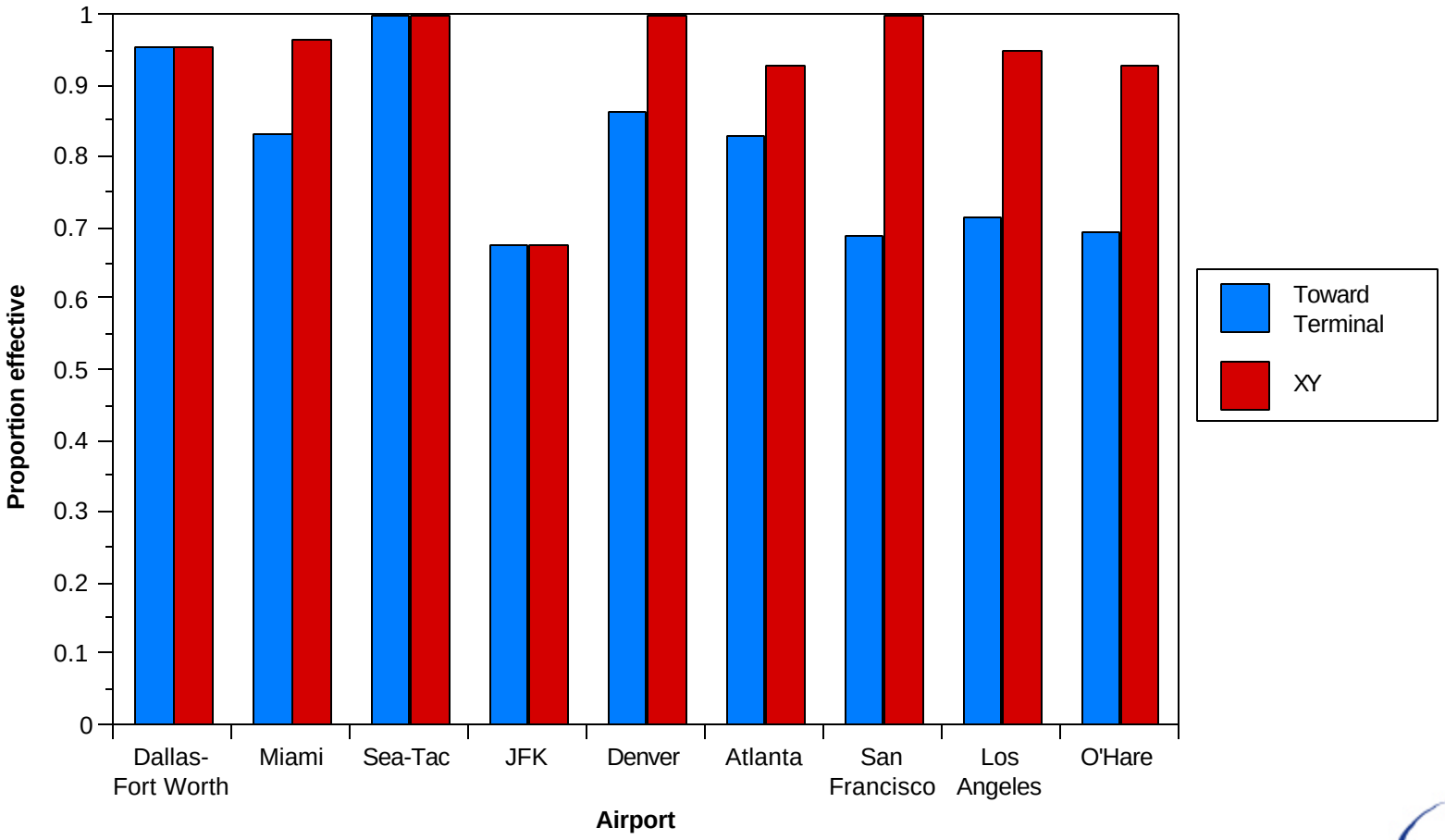
- Used the database from the NASA flight simulator
- Aircraft position and heading used to determine what objects should be visible
  - Yellow lines
  - Signs
  - Distance from each
- Work is in progress on degrading the representation of text at longer distances
  - ACT-R/PM's Vision Module contains a "best guess" mechanism for degraded input
  - This is another potential error source

Task Environment Model

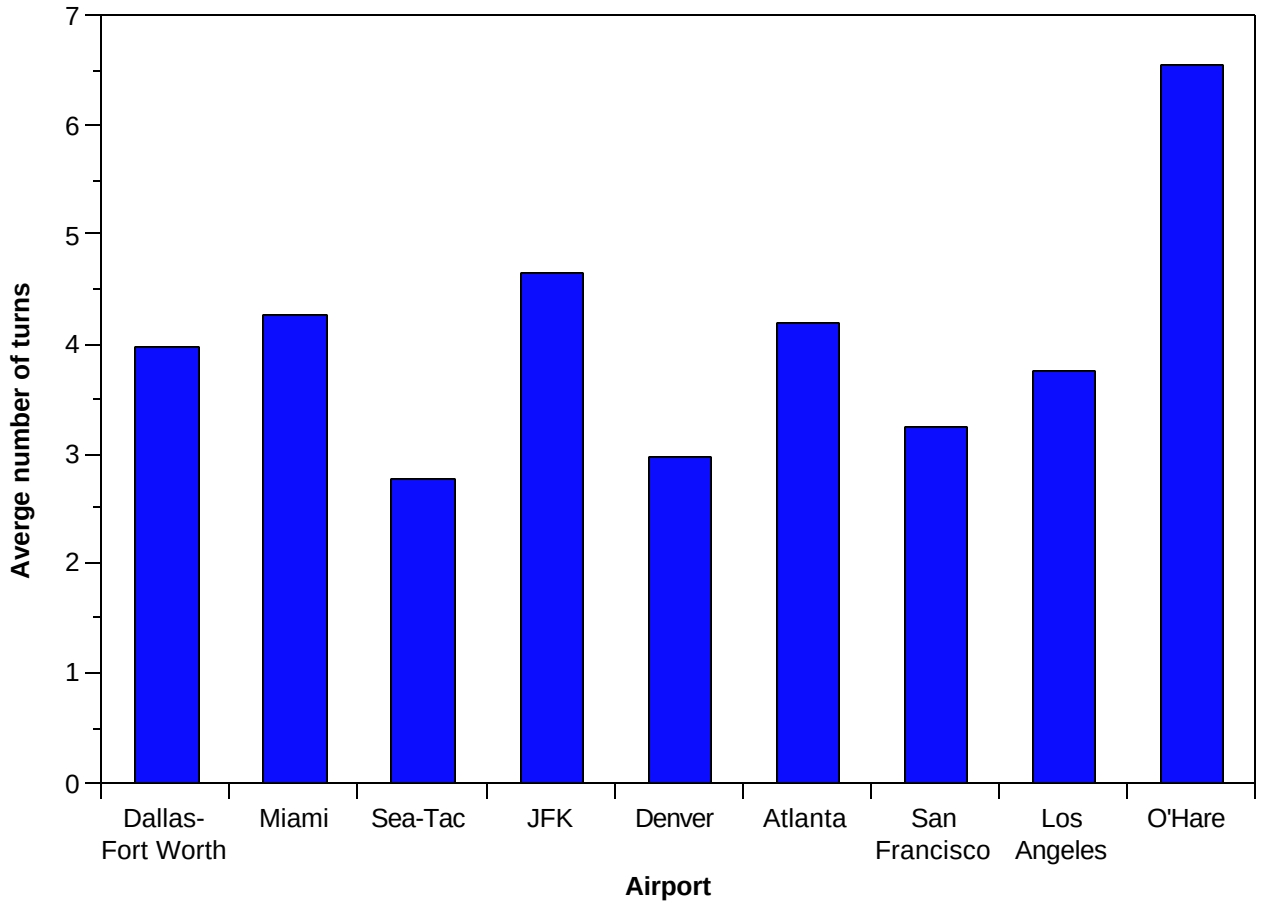
- SME provided us with Jepp charts for other airports with “typical” taxi routes indicated
  - Different airports
    - Near grids: Atlanta, Dallas, SeaTac, Denver
    - More like O’Hare: JFK
    - In between: San Francisco, Miami, Los Angeles
- Discoveries:
  - “XY” heuristic is good across the board
  - “Toward terminal” heuristic is good some places, but not at O’Hare
  - All turns where both heuristics fail, at least one error was made!


S120, T200, ST175, TT600, DDT850
RWY 18L-36R
S120, T200, ST175, TT600, DDT850
RWY 18R-36L
S120, T200, ST175, TT600, DDT850
FIRE STATION No. 3
EAST AIR FREIGHT
FEDERAL EXPRESS
9000 X 200
0.5% DOWN
129.3°
ELEV 553
ILS HOLD
ELEV 563
174.3°
0.6% UP
8500 X 150
354.3°
0.6% DOWN
ELEV 576
ELEV 524
HANGAR
EAST CONTROL TOWER
FIRE STATION No. 1
11388 X 150
ELEV 562
ILS HOLD
13401 X 200
ELEV 563
ELEV 567
NE HOLD PAD
SE HOLD PAD
AIRFREIGHT
U. S. CUSTOMS
2E
3E
4E
2W
U. S. CUSTOMS
HOTEL
CENTRAL CONTROL TOWER
799
CENTRAL TERMINAL AREA
GENERAL AVIATION PARKING
Rwys 13L and 31R ldg 8375'
Rwys 18L and 36R ldg 10388'
SW HOLD PAD
ELEV 596
11388 X 200
ELEV 576
ILS HOLD
11388 X 150
ELEV 582
FIELD ELEV 603
ILS HOLD
FIRE STATION No. 2
UPS RAMP
WEST CONTROL TOWER
WEST AIR FREIGHT
HANGARS
ELEV 577
313.1°
FIRE STATION
VAR
97°01' W
97°02' W
97°03' W
97°04' W

Heuristic Effectiveness



Average Route Length



Error Behavior

- Several sources
  - Retrieval failure/mis-retrieval
    - Exacerbated by memory-based workload
  - Use of less accurate strategies to meet time constraints
    - Exacerbated by temporal workload
  - Perceptual failures
- Coverage
  - The decision errors appeared to be at least explained
  - Prediction is difficult
    - Need a priori basis for setting all parameters for all pilots
  - Some execution errors can be modeled

Possible Future Extensions

- Near term
  - Monte Carlo simulations to explore parameter sensitivity
- Already mentioned
  - Degraded perceptual inputs
- Questions to answer
  - Are there other decision strategies? If so, how long do they take and how well do they work?
- Adding FO model
  - Would need more detailed information about FO tasks to help determine behavior of that model

ACT-R Issues: 3D Vision

- Vision Module in RPM originally designed for 2D visual world (e.g. computer screen)
- In some sense, this is still true of a flight simulator, but is a terrible mis-representation
- Augmented visual representation beyond XY position to add “depth” or “distance” attribute
  - Same kinds of operations supported, such as selection based on max value
  - Lack any real notion of occlusion

ACT-R Issues: PG-C

- Decision strategy selection not really guided by PG-C
- Our model **explicitly** represents our best guess at the average time taken by each turn-selection strategy
  - Model never chooses a strategy that takes longer than the time available to make a decision
- Want highest P given maximum allowable C, so we set production C estimates (by setting b) to be equal, even though this isn't really quite correct

ACT-R Issues: Rapid visual updating

- To model aircraft dynamics correctly, the “world” has to be updated very often
  - Linear approximations to diffeq issues
- This means the visual world changes a LOT
- Rebuilding the entire visicon and figuring out what ought to be marked as “new” each time is tricky
- Basically, we update the plane position and such as often as possible and “lock out” visual upates
  - Every 250 ms or so
- This is not solved to my satisfaction

ACT-R Issues: 4.0 vs. 5.0

- As noted, this is a 4.0 model
- Not 100% clear to me yet what effects a 5.0 port would have
- Speculations:
  - Event-driven system should make device updating better
  - There are probably several places where ACT-R will be "faster" on the basis of asynchronous memory retrieval
    - This is almost certainly good
  - Goal management
    - Goal decay and such is probably OK
    - Makes extensive use of call-return mechanism, which might yield a porting problem

Other credits

- NASA
- Brian Webster
- Michael Fleetwood
- Chris Fick